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Impact of Army Architecture Evaluations

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Executive Summary

On August 12, 2002, the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT)) initiated the Army's Strategic Software Improvement Program (ASSIP). The purpose of the ASSIP is to improve the way in which the Army acquires software-intensive systems.

As part of the ASSIP, the Army funded the Carnegie Mellon® Software Engineering Institute (SEI) to conduct software architecture evaluations on Army systems using the SEI Architecture Tradeoff Analysis Method® (ATAM®) from 2002 through 2007. The ATAM is a method for analyzing architectures relative to their quality attribute requirements. ATAM-based architecture evaluations identify architecture risks, which are potentially problematic architectural decisions relative to the system's ability to satisfy its quality attribute requirements. Additionally, in cases when a system's architecture did not exist or was too immature to evaluate, the ASSIP sponsored SEI Quality Attribute Workshops (QAWs). The QAW is a method for eliciting quality attribute requirements that are essential for designing a system's architecture. During this same period, several other Army programs funded their own ATAM evaluations and QAWs. A total of 12 Army programs conducted ATAM or QAW evaluations during this period, and all participated in this study.

The purpose of this report is to convey the results of a survey that elicited the perceived impact the ATAM evaluations and QAWs had on system quality and the practices of the acquisition organization. The survey was constructed to determine how the programs were impacted in terms of the quality of the system; the practices of the involved program office, stakeholders, and suppliers; and the overall perceived value of the ATAM and/or QAW engagements.

Overall, the survey results suggest that the Army programs received benefit from the use of the ATAM and QAW, as shown in the following results:

- Six of the 12 programs reported that it cost less to use the QAW to elicit quality attribute requirements and the ATAM to evaluate their software architecture than the techniques they traditionally have used. Moreover, independent of whether the programs reported less or more cost, they all reported results that were at least as good, and often better, than the results they traditionally obtained.
- Ten of the 12 programs that conducted an ATAM evaluation and/or QAW reported that the method provided an informed basis for the program office and the supplier to better understand and control the software development cost and schedule.
- All programs found that using the ATAM and/or QAW increased their understanding of the system's quality attribute requirements, design decisions, and risks. This is consistent with what we heard when we held an ASSIP-sponsored Army architecture workshop in 2007, where the participants told us that using the ATAM and/or QAW could be used to reduce acquisition risk for the DoD.

® Carnegie Mellon, Architecture Tradeoff Analysis Method, and ATAM are registered in the U.S. Patent and Trademark Office by Carnegie Mellon University.

- Overall, the programs felt that the use of the ATAM and/or QAW provided a good mechanism for the program office, suppliers, and stakeholders to communicate their needs and understand how they are met.
- A minority of the respondents felt that using the methods would result in overall cost and schedule reductions for their respective programs. Further analysis revealed that the context of use had a significant impact on this response. For example, a lack of commitment (or mandate) to mitigate the risks found by evaluating the architecture would obviously limit the ultimate impact of the evaluation.
- A majority of the respondents felt that using the ATAM and/or QAW led to an improved architecture (8 of 12), and a higher quality system (6 of 10). Again, contextual factors had a significant impact on these findings, leading us to believe that under appropriate acquisition conditions these practices are very likely to have a positive impact on system quality.

In summary, the data gathered for this study confirms that the use of ATAM-based architecture evaluations and QAWs are generally beneficial to DoD system acquisitions and suggests that maximal benefit is achievable only if architecture-centric practices are built into the acquisition process.

Abstract

The Army Strategic Software Improvement Program (ASSIP) is a multiyear effort targeted at improving the way in which the Army acquires software-intensive systems. The ASSIP has funded a number of programs, in conjunction with the Carnegie Mellon® Software Engineering Institute (SEI), to conduct software architecture evaluations using the SEI Architecture Tradeoff Analysis Method® (ATAM®). Additionally, in cases when a system's architecture did not exist or was not ready to evaluate, the ASSIP sponsored SEI Quality Attribute Workshops (QAWs). During the period of this effort, several other programs funded their own ATAM evaluations and QAWs. The goal of this study was to determine the benefits associated with using the ATAM and QAW.

This special report describes the results of a study of the impact that the ATAM evaluations and QAWs had on Army programs. All 12 programs that used the ATAM and/or QAW responded to a questionnaire whose objective was to determine the impact of the experience in terms of the quality of the system, the practices of the involved program office, stakeholders, and suppliers, and the overall value of the engagement.

The data gathered confirms that the use of ATAM-based architecture evaluations and QAWs are generally beneficial to system acquisitions and suggests that maximal benefit is achievable only if architecture-centric practices are built into the acquisition process.

1 Introduction

On August 12, 2002, the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT)) initiated the Army's Strategic Software Improvement Program (ASSIP). The purpose of the ASSIP is to improve the way in which the Army acquires software-intensive systems. The ASSIP is predicated on the idea that better acquisition practices (such as rigorous evaluation of software architectures developed for the systems being acquired) will lead to better systems and overall results [Blanchette 2007].

As part of the ASSIP, the Army funded the Carnegie Mellon® Software Engineering Institute (SEI) to conduct software architecture evaluations on nine Army systems using the SEI Architecture Tradeoff Analysis Method® (ATAM®). The ATAM is a method for evaluating architectures relative to their quality attribute[1] requirements. ATAM-based architecture evaluations identify architecture risks, which are potentially problematic architectural decisions relative to the system's ability to satisfy its quality attribute requirements. System development suppliers,[2] as the architects of their respective systems, participated in the ATAM evaluations by presenting their architectures to the evaluation teams, describing how the architecture satisfies each of the quality attribute scenarios, listening and responding to the teams' findings, and, ultimately, by taking appropriate actions based on those findings.

Additionally, in cases when a system's architecture did not exist or was too immature to evaluate, the ASSIP sponsored a companion method—the SEI Quality Attribute Workshop (QAW)—to elicit quality attribute requirements. During this same period, several other Army programs funded their own ATAM evaluations and QAWs. A total of 12 Army programs conducted ATAM or QAW evaluations during this period, and all participated in this study.

In addition to funding these architecture-related engagements, the ASSIP also funded an Army Software Architecture Workshop that the SEI co-hosted in Pittsburgh, PA during May of 2007. The goal of the workshop was to provide a forum for participants to share lessons learned in using the ATAM and QAW and to examine enablers and barriers to adoption. Participants clearly indicated that they found their experiences with ATAM/QAW techniques useful. Some of the benefits cited were

- explicit capture of the programs' business and mission goals and desired system quality attributes
- rigorous specification and prioritization of the system's desired system quality attributes in an unambiguous and testable form
- improved (or first ever) software architecture documentation

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1 Quality attribute requirements are also referred to as nonfunctional requirements.

2 Note that the term *supplier* refers to the organization responsible for supplying the software, which could be a contractor, subcontractors, software engineering center (SEC), or other software development organization.

- discovery of software architecture risks and overarching risk themes that were previously unknown and which traditionally do not play a role in a preliminary design review (PDR)

Yet, for all the positive feedback, the workshop could not answer, in any quantitative manner, challenging questions about the value of ATAM/QAW practices. Indeed, one of the recommendations was to develop a good case study that includes return on investment (ROI) data, with the expectation that such a study would provide the necessary impetus for broader, more consistent adoption of software architecture practices across Army acquisition programs.

The difficulty in determining the ROI for ATAM/QAW practices stems from two facts: (1) DoD programs do not traditionally obtain detailed software cost data on development contracts and (2) the primary payoff of conducting an architecture evaluation is cost avoidance due to mitigating risks that would otherwise require costly rework downstream. The study discussed in this report is a first attempt at determining the ROI of ATAM/QAW practices in a more systematic manner. The study demonstrates value in taking steps towards a more disciplined approach to measuring results by moving from measuring reactions and perceived value to measuring what participants learned during the ATAM/QAW, what knowledge and skills they applied after the engagement, and what the consequences were in terms of impact on programmatics, product, and practices.

1.1 Objective of This Study

The objective of the study documented in this report was to determine the value the Army programs received from using the ATAM and QAW. ASA(ALT), in particular, desired evidence that the Army programs had saved money, seen substantial changes or improvements, and overall had benefitted from a positive impact of the ASSIP-funded effort in architecture evaluation. This impact data would enable the Army decide whether these practices should be considered for broad adoption across the Army. Accordingly, the SEI was tasked by ASA(ALT) to determine and report on the impact of these architecture practices and lessons learned on Army programs. Table 1 identifies the Army programs and the architecture-related practices they were surveyed about in this study.

Table 1: Participating Army Programs and the Architecture-Related Practices Employed

Army Programs (in alphabetical order)	ATAM	QAW
Aerial Common Sensor (ACS)	✓	✓
Army Battle Command System (ABCS)		✓
Command Post of the Future (CPoF)	✓	
Common Avionics Architecture System (CAAS)	✓	
Distributed Common Ground Station – Army (DCGS-A)	✓	✓
Force XXI Battle Command, Brigade-and-Below (FBCB2)	✓	
Future Combat Systems (FCS)	✓	✓
Integrated Fired Control (IFC)	✓	✓
Joint Tactical Common Operational Picture Workstation (JTCW)	✓	
Manned/Unmanned Common Architecture Program (MCAP)	✓	
One Semi-Automated Forces (OneSAF)	✓	
Warfighter Information Network – Tactical (WIN-T)	✓	

Collectively, these 12 Army programs conducted 11 ATAM architecture evaluations and 5 QAWs from 2002 through 2007.

1.2 Basis for Evaluating the Impact of ATAM and QAW Architecture Practices

A questionnaire was developed to survey the experiences of the 12 Army programs that participated in the ATAM/QAW engagements. The questionnaire was designed to elicit information on the impact of using the ATAM and QAW on quality improvements that were realized by the Army programs. The quality improvements of interest were

- programmatic improvements (cost and schedule aspects)
- product improvements (system and software development)
- practice improvements (acquisition and development practices)

These improvements were considered from the standpoint of when they were realized—that is, whether they occurred during the preparation and execution of the ATAM and QAW or afterwards. Table 2 depicts the matrix that resulted from considering the three noted quality improvements of interest with respect to when they were realized. Each cell of the matrix was then used to distill the topics for the questionnaire.[3]

Table 2: Criteria for Evaluating the Impact of Army ATAMs and QAWs

Quality Improvements	Preparation and Execution	Post-Engagement Activities
Programmatic (Cost and Schedule)	Effective in terms of • cost • effort	Improved • program schedule performance • program cost performance
Product (System and Software)	Clarification, discovery, and use of • quality attribute requirements • architecture documentation • risks and risk themes	Improved • software architecture • system qualities/capabilities • warfighter effectiveness
Practices (Acquisition and Development)	Foster communication among program office, suppliers, and stakeholders to • understand and control cost and schedule • communicate quality attribute requirements • evaluate the architecture • improve the architecture	Organizational changes • use of the results • use of the practices in the short term • adoption of the concepts • adoption of the methods • training personnel to conduct the methods

Programmatic considerations for preparation and execution led to questions that addressed cost and effort aspects of an ATAM evaluation or QAW as compared to how the software architecture is typically evaluated and requirements are typically elicited. Considering post activities led to questions that addressed long-term improvements in cost and schedule performance.

Product considerations for preparation and execution led to questions that addressed the clarification, discovery, and use of quality attribute requirements, architecture documentation, and archi-

[3] Note that one questionnaire was developed for both the ATAM and QAW although only a subset of the questions was relevant for the QAW.

tecture risks. Considering post activities led to questions that addressed the long-term improvements in system quality and warfighter effectiveness.

Practice considerations for preparation and execution led to questions that addressed communication among the stakeholders and use of the results of the engagement as an informed basis on which to improve acquisition practices (especially those that involved communication between the program and the supplier). Considering follow-on activities led to questions that addressed changes in the behavior of the organization in both the short term (e.g., use of the results, use of practices to gather additional results) and in the longer term (e.g., adopting new practices and investing in training).

1.3 The Program Impact Questionnaire

The *quality improvements* of interest were used as the basis for creating a questionnaire to elicit the perceived impact the ATAM evaluations and QAWs had on system quality and the practices of the acquisition organization.

The survey was constructed to determine how the programs were impacted in terms of quality and cost; whether there were follow-on (i.e., post-ATAM/QAW) activities, whether the QAW or ATAM was subsequently adopted as a future program practice, and what the overall value of the ATAM/QAW engagements were perceived to be.

The questionnaire was organized into four sections:

1. Conducting the ATAM/QAW—elicited information about product and practice improvements during preparation and execution of the method
2. Follow-On ATAM/QAW Activities—elicited information about practice improvements during the post activities, focusing on how the engagement affected the immediate behavior of the organization
3. Adoption of ATAM/QAW—elicited information about practice improvements during the post activities, focusing on how the engagement affected the long-term acquisition practices leading to adoption of ATAM and/or QAW as part of acquisition practices.
4. Overall Impact —elicited information about short-term and long-term programmatic improvements and long-term product improvements; in addition, it provided survey respondents an opportunity to share comments on how they perceived the overall impact of the engagement and about the engagement in general.

Survey respondents were also asked to comment on the circumstances that influenced their responses. This information helped us understand the contextual factors that might influence the findings and the appropriate acquisition conditions under which these practices could be applied to have a greater impact on system quality.

We collected data from each of the participating programs with the understanding that the results would be aggregated across the programs, and data specific to a program would not be revealed.

1.4 Organization of This Report

This special report is organized as follows:

- Section 2 presents the findings and provides a measure of the overall estimated value the Army programs received from these engagements, in terms of the quality improvements that were realized.
- Section 3 describes the context (with respect to planning, timing, need, motivation, accommodation, and follow through) in which the programs conducted the ATAM/QAW and the effect that context had on benefiting from the results.
- Section 4 draws conclusions for incorporating architecture practices in system acquisitions that could aid Army programs in achieving maximum impact.

The appendices include a list of acronyms used in the report, an overview of the ATAM and QAW, the ATAM/QAW Impact Questionnaire that was completed by each of the programs, and the summary comments regarding impact provided by the respondents.

2 Impact of Army-Sponsored ATAMs/QAWs

This section considers the findings from the perspectives of the quality improvements of interest: programmatic, product, and practice improvements.

2.1 Programmatic Improvements (Cost and Schedule Aspects)

The responses relating to conducting the ATAM/QAW engagements and the post-engagement activities provide different perspectives on impact with respect to cost and schedule.

Findings relating to conducting the ATAM/QAW

We asked respondents to compare the cost (in terms of up-front expense and effort) of conducting the ATAM/QAW to the means, if any, they would otherwise have used to elicit and specify quality attribute requirements and evaluate the software architecture. To make a fair comparison, it is important to consider the level of quality being produced for the given cost. So we asked respondents to make comparisons from two points of view: (1) compare the cost of applying the alternative means to produce results of the same level of quality as the ATAM/QAW, and (2) compare the quality of the results (e.g., quality attribute scenarios, architecture documentation, and architecture risks) of the alternative means as they are traditionally used with those of the ATAM/QAW.

The results can be arranged in the four quadrants as seen in Table 3, which shows how the cost and quality of the ATAM/QAW are perceived, compared to the other techniques traditionally employed by the acquisition organizations. (One program did not respond to the questions for this category.)

Table 3: Quality of ATAM/QAW Output vs. Other Techniques (shown as number of programs)

Conducting the method	Better (or same)	Lesser
Cheaper (or same)	6	1
Costlier	4	0

As seen from the data in the column headed *Better (or same)* in Table 3, 10 programs reported that the ATAM/QAW produced results that were the same or better quality. The one program that reported lesser quality did so for the following reason: "The ATAM is a coarse grained (time-constrained) process for evaluating architecture not suited for precise analysis and delving deep into details of architecture as some other means do to produce quality products." However, that program also indicated that the ATAM/QAW involves less cost and effort than traditional means used to achieve the same level of quality and acknowledged that the "QAW and ATAM provided benefits deemed substantial enough to warrant adoption for future contracts."

Also, as shown in the row labeled *Cheaper (or same)* in Table 3, seven programs reported that the ATAM/QAW engagement was the same or less cost than their other means to elicit and specify quality attribute requirements or evaluate architecture design.

Of the four programs that reported more cost (see the row labeled *Costlier*), two responded that the quality of the results was higher and they did not have other means of analysis; they indicated that they would use ATAM/QAW methods again:

- "ATAM will again be used for architecture evaluation."
- "If anything, we should have done more of them [ATAMs and QAWs] to continually reconfirm nonfunctional requirements, update the architecture, and get buy-in to the architecture."

The other two indicated that the quality of the results was the same as that for other means of analysis and offered observations related to the timing of the engagement for why a greater benefit was not achieved:

- "Unfortunately, due to the breadth of impact of the architecture, the results were not amenable to implementation except at great cost and time. ATAMs should be conducted at the initiation of programs where architectural change can be readily integrated into the program development."
- "The benefit of the ATAM was equal to its cost. The ATAM was conducted too soon in the system life cycle . . . The ATAM and QAW has a positive impact to the DoDAF architecture construction."

Interpretation of the Findings

Overall, the data show that the ATAM and QAW are effective techniques for eliciting quality attribute requirements and analyzing software architectures; in some cases, they are more cost-effective than traditional analysis methods.

This observation echoes the findings of the 2007 Army Architecture Workshop. There, workshop participants concluded that the ATAM offers a practical way of evaluating a system against its quality attribute requirements that typically take "a back seat" to the functional requirements. That is, traditionally acquisition programs focus on functional requirements (at the expense of the quality attribute requirements) to the detriment of the fielded system's long-term acceptability.

Findings relating to post-engagement activities

Looking at the responses related to post-engagement actions provides another perspective on impact with respect to cost and schedule. Ten programs acknowledged that the ATAM/QAW methods would be helpful in providing "an informed basis for the program office and the supplier to better understand and control the software development cost and schedule." The two that did not offered these explanations:

- "The software architecture was not evaluated." (This respondent viewed the evaluation as being conducted on the "system architecture.")
- "Being existent on multiple platforms, [the architecture] is not open to change except at great cost and schedule."

Four respondents indicated that the use of the methods did contribute to longer term cost and schedule improvement. (Three programs did not respond to the questions for this category.) Three of the five programs that did not respond favorably in this category offered these explanations:

- "Since the ATAM results were not substantially used, no impact was experienced."
- "The results of the QAW and ATAM were not considered factors for the . . . acquisition program baseline."
- "Because the ATAM was done late in the development process . . . the ATAM mostly validated the…architecture and approach."

These programs conducted their QAW/ATAM engagements late in the development cycle, which limited their flexibility in reacting to the findings. Another program reported that "these benefits were still not realized because the contractor has never really embraced the [concepts]." In this case, the development contractor has not committed in equal measure with the project management office (PMO) to using the ATAM/QAW techniques, thus limiting their effective application. The final program responding unfavorably on this point reported that "this was a developmental system under examination, the project was not under pressure to exit with 'fieldable' software." In this case, the program was conducting a research and development project that was close to its demonstration phase.

Interpretation of the Findings
While there is potential for long-term cost and schedule benefits from employing ATAM/QAW, circumstances can prevent realization of that value. In any case, in order to achieve maximum value, the results of the evaluation must be accepted and acted upon, and both PMO and contractor must agree as to the follow on actions to be taken. This acceptance and agreement are only likely to happen when a proactive approach is taken, and compliance is contractually required.

2.2 Product Improvements (System and Software Development)

The responses relating to conducting the ATAM/QAW engagements and the post-engagement activities provide different perspectives on impact with respect to system and software development.

Findings relating to conducting the ATAM/QAW

The responses to product improvement questions related to conducting the ATAM/QAW showed that all programs acknowledged favorable impact of the ATAM/QAW techniques on their understanding of three key development artifacts: the quality attributes, architecture, and risks.

Overall, four programs reported moderate results in at least one category; one program reported moderate results across the three artifacts; two reported moderate results in two artifacts and significant results in the other one; one reported moderate results in one artifact and significant results in the other two.

As Figure 1 shows, each program reported at least moderate improvements in all three artifacts. The majority of programs, in fact, rated results to be significant in each of the artifacts. One program reported very substantial results with respect to architecture, and another for risks.

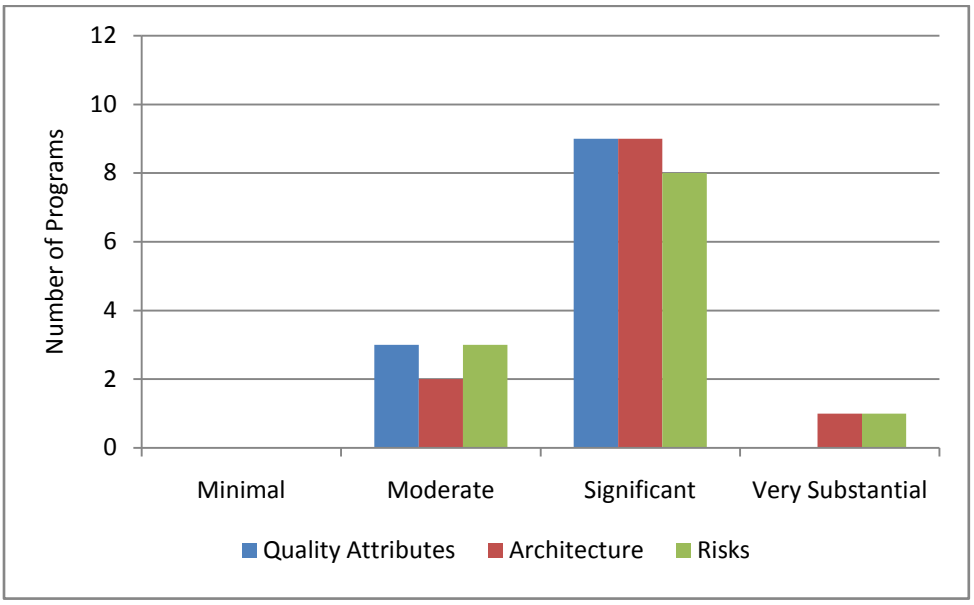

Figure 1: Architecturally Significant Artifacts Enhanced by ATAM/QAW

Interpretation of the Findings
These results demonstrate that the architecture team is able to use ATAM/QAW to achieve an understanding of stakeholder expectations for the system and the implications of architectural decisions on user needs. Moreover, ATAM/QAW provides the architecture team and system stakeholders with the means to develop a joint understanding of the relevant risks to success.

Findings relating to post-engagement activities

Ultimately, the goal of ATAM/QAW is to achieve a better product. The responses related to post-engagement product improvements provide another perspective on impact. Eight programs acknowledged that the ATAM/QAW "improved the architecture." Six programs indicated the use of the methods contributed to the overall system quality and/or warfighter effectiveness. (Two programs did not respond to the questions for this category). The programs that reported minimal results are a subset of those that reported minimal results for longer-term cost and schedule improvement; the explanations for those results are reported in Section 2.1.

Interpretation of the Findings
The ATAM and QAW have yielded tangible benefits for Army programs, including clarified quality attribute requirements, improved architecture documentation, and reduced software design risk. All of these benefits contribute to a tangible result: better quality products for the warfighter. These observations are consistent with the findings of the 2007 Army architecture workshop, which noted the ability of the ATAM/QAW to reduce software acquisition risk, especially in the DoD environment. As one workshop participant stated, "It was just an excellent mechanism for getting a team to work together to discover risks and inconsistencies that would otherwise go undetected."

2.3 Practice Improvements (Acquisition and Development Practices)

The responses relating to conducting the ATAM/QAW engagements and the post-engagement activities provide different perspectives on impact with respect to acquisition and development practices.

Findings relating to conducting the ATAM/QAW

The responses to practice improvement questions related to conducting the ATAM/QAW showed that the value of the ATAM/QAW in fostering communication among stakeholders was rated highly. The programs also acknowledged that the ATAM/QAW provided an informed basis for the program office, suppliers, and stakeholders to communicate their needs and understand how they are met.

As Figure 2 shows, the majority of programs reported very substantial enhancement of communication, while several others reported significant results. The one program that reported minimal results offered this explanation: "It appeared to stakeholders that these activities did not warrant action since neither the time or funds were readily available to support them."

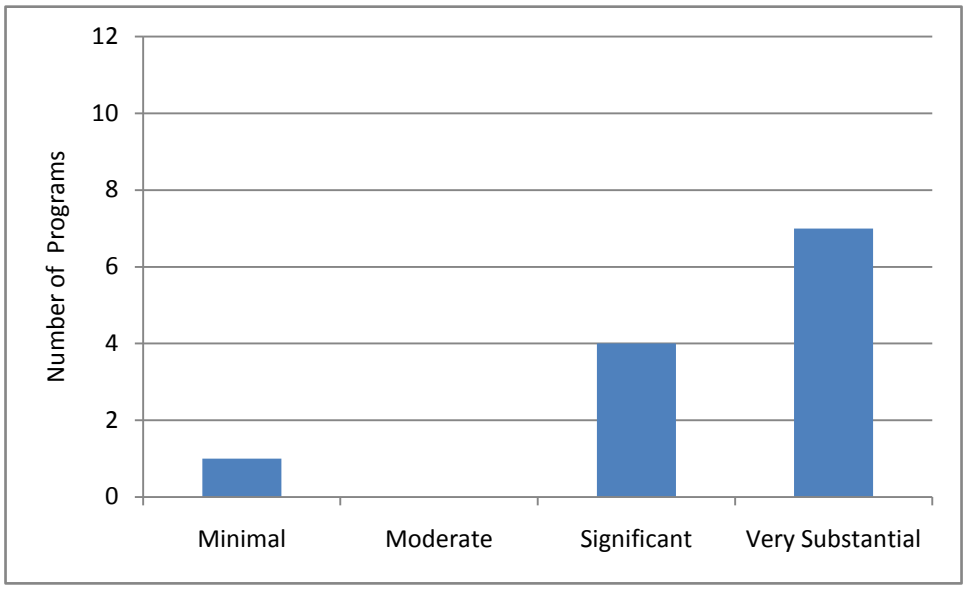

Figure 2: Communication Enhanced by ATAM/QAW

Interpretation of the Findings
The significance of these results is that stakeholders, collectively, are able to use ATAM/QAW to achieve a common understanding of the system under development, making it more likely that the completed product will address stakeholder expectations and user needs, thereby improving chances for program success.

Findings relating to post-engagement activities

Improving practices that support development of a better product is a goal of the ATAM/QAW. Thus, a final measure of the impact of these techniques is the extent to which programs

incorporate, or *transition*, them into their own acqusition and development practices. The responses related to post-engagement practice improvements can be grouped into five categories, each building on the next from a basic level (numbered as "1") up through increasing levels of sophistication:

1. **All programs reported some use of the artifacts produced by the ATAM/QAW.** For example, some put the quality attribute scenarios they developed into a requirements tracking system, others improved their architecture documentation, and others formally tracked risks discovered durng the evaluation.
2. **Eleven programs reported using the techniques** of the ATAM/QAW methods to uncover additional risks by, for example, refining or analyzing additional scenarios.
3. **Nine programs reported adopting the concepts** of quality attribute requirements elicitation and architecture evaluation.
4. **Seven programs reported adopting the ATAM/QAW methods**. (i.e., by using or specifying the use of the practices).
5. **Three programs reported investment in formal ATAM evaluation training**.

Categories 1 and 2 represent limited transition, in that investment in the techniques occurred in the short term to achieve an immediate impact. Categories 3, 4, and 5 represent more sustained investment in adoption and training for a longer term impact.

Furthermore, since organizations are willing to invest time and effort, transition indicates the value that they place on the ATAM/QAW. One respondent commented, "The practices were adopted because they provided a well-defined process for architecture evaluation." Another offered this comment:

> *The ATAM process provides an excellent disciplined approach for identifying driving quality attributes, associating those attributes with specific use cases, and then describing specific architectural patterns that support, restrict, or are in contention with other quality attributes. For a software intensive system the ATAM/QAW process would be very beneficial at the start of the program. For programs already underway the ATAM/QAW provides an excellent opportunity to assess and strengthen or correct architectural products and process through structured risk identification and acknowledgement process.*

Interpretation of the Findings

These observations are consistent with the findings of the 2007 Army architecture workshop, which noted that the ATAM and QAW give stakeholders "a voice" in the development process, especially in the DoD environment, and that the Army and its support contractors have been receptive to using the QAW and ATAM, demonstrating that the methods can be performed collaboratively without creating an adversarial environment. Workshop participants concluded that standardizing the use of methods such as the ATAM and QAW makes training easily transferable from one project to another and provides a practical means for capturing lessons learned and improving Army management and conduction of its software-intensive system acquisitions.

3 Factors Affecting Impact

The questionnaire asked programs to comment on the activities they did or did not perform or plan to adopt. Respondents were asked why they did or did not perform the activities and what factors contributed to the success of performing the activities or were obstacles that hindered them from doing so.

In the course of studying and analyzing the impact, it became apparent that the context in which the methods were used had a significant impact on responses. A number of factors played a major role in determining the extent to which the acquisition organizations benefited from the architecture practices. The six contextual factors that played a significant role involved the *planning, accommodation,* and *timing* of these engagements and the *need*, *motivation*, and *follow through* for these engagements.

We rated each of the programs for each factor along a 3-point scale, with 1 indicating an undesirable context, 3 indicating a desirable context, and 2 indicating something in between. Table 4 shows the 12 programs and their ratings in terms of the 6 contextual factors.

Table 4: Overview of Contextual Factors Affecting the Impact of Army ATAMs/QAWs[4]

Program	Planning	Timing	Need	Motivation	Accommodation	Follow Through
1	1	1	1	1	1	1
2	1	1	2	1	1	1
3	1	1	2	1	1	2
4	2	1	2	2	1	2
5	2	2	2	2	2	2
6	1	2	3	3	2	2
7	1	2	3	3	2	3
8	1	3	2	3	2	3
9	2	3	3	3	2	2
10	1	1	3	3	3	3
11	1	3	3	3	3	3
12	3	3	3	3	3	3

The factors are defined in the sections that follow, together with an interpretation of the results. While the number of programs provides too small a data sample to show a statistical correlation, we see evidence that a program with a more desirable context experiences higher value from their ATAM/QAW experience than a program with overall lower ratings.

3.1 Planning and Accommodation

Planning and accommodation have to do with the contractual context. In general, if the ATAM/QAW is not written into the original request for proposal (RFP) or contract then the plan-

[4] The programs are listed according to their contextual factor rankings and do not correspond to the alphabetical listing that was given earlier.

ning for it is "reactive"; the program office typically must consider contract modifications or scope adjustments, often at additional costs. The reactive case is therefore less desirable than the proactive case, where the ATAM/QAW is considered early in the acquisition cycle. Proactive architecture evaluations are preplanned and integrated into the RFP and contract as an integral part of the acquisition planning effort. The benefits of a proactive approach are that all affected parties are in agreement from the outset of the RFP/contract and the cost and schedule of the evaluation are known entities that are included as an integral part of each offeror's technical and cost proposals.

The contractual context for the majority of the engagements discussed in this report was reactive; with only one being proactive. This is understandable, given that these engagements occurred early in the ASSIP program with programs that were already underway. The consequence of executing the ATAM/QAW reactively is that there were impediments to achieving maximal value.

Some of the impediments of reactive planning could be overcome through accommodation between the program office, stakeholders, and the supplier by considering the existing (or proposed) contractual circumstances to ensure architecture practices can be appropriately accommodated within an acceptable cost and schedule window. When an ATAM/QAW is done reactively, significant work is needed to contractually accommodate the ATAM/QAW or the engagement (including follow up activities) can become problematic. In such cases, a program may encounter "push back" from the system developer because adding unplanned activities and events after the original contract is signed is an added cost item that will impact the overall schedule. Introducing new architecture-centric practices within the confines of an existing contract is more costly than a proactive approach; for example, architecture documentation is usually deficient or may have to be created anew. Without a proactive approach, more effort will have to be expended negotiating with the system developer to get the level of cooperation and follow through that is needed.

Having a champion or an experienced ATAM evaluator who has previously coordinated such efforts can help alleviate some of these obstacles. Arrangements must be made to ensure the participation of key stakeholders and to obtain the active cooperation of the system contractor. Such accommodation involves contractual negotiations to reach agreement on funding and schedule allowances. Even in those cases where both planning and accommodation were rated as undesirable, once the technical people could be gathered to conduct the ATAM/QAW, the disciplined process provided a means for the participants to engage and obtain value during the engagement, as indicated by the preparation and execution results reported in Section 2. However, these factors were more serious impediments to using the results, especially *after* the engagement, as indicated by the comments:

- "Given where we are at now in not [following up with some of these practices] – chasing functionality in lieu of quality, we realize benefits of adopting in our new contracts."
- "The nature of the contract at the time … precluded [using the developed quality attribute scenarios] due to cost and schedule impacts to the Acquisition Program Baseline." This same program also noted that the architectural risks identified during the ATAM evaluation were not tracked or managed for the same reason. Such statements illustrate a common paradox in program development: citing cost as the reason for not taking problem avoidance measures even though the result of that inaction may be more expensive problem resolutions later on.

- "Software architecture documentation for the candidate architecture evaluated at the ATAM had limited access and was not under the purview of the PM [program manager]. This was a lesson learned that contributed to the specification of specific contract deliverables for creating, delivering, managing, and evolving software architecture documentation in a subsequent solicitation." Here, the PMO recognized the need to have access to the contractor-developed architecture documentation and made the appropriate adjustments for future contracts.

Insufficient language in the contract precludes adding activities or accommodating other changes to follow through with the evaluation results; however, even in situations where there is a contractual obligation to use the ATAM/QAW results, there can still be a risk if there is no follow through from the program office. As one respondent reported, "Contractor was contractually obligated to [update architecture documentation based on ATAM results]. PMO realized the benefits but the intent of the architecture was never really followed or instantiated properly for products."

While the preceding observations tell a cautionary tale about ensuring commitment from suppliers and stakeholders, the PMO does have some obligation for accommodation and follow through. For instance, the program office in one case made changes in their processes to provide better support for review and management: "Before the ATAM these attributes had been defined by the contractor and were well known by the software development staff, but the government project office was less familiar with them. So, we found it logical to incorporate the scenario requirements into our review and management of the effort."

3.2 Timing

Timing—that is, when in the system development life cycle the ATAM/QAW are deployed—can significantly affect the technical outcome in terms of the number and type of risks that are identified and their timely and cost effective resolution. Conducting an ATAM/QAW too early or too late in the system development life cycle (e.g., after the system has already been fielded for sometime) does not yield the same benefit as conducting it at a favorable time, such as in the formative stages of architectural design. Another more opportune time is when a major upgrade is being considered, which would warrant careful consideration of the potential impact of new requirements on the existing architectural design. Ideally, an architecture evaluation would be conducted before the system's PDR or, at the very latest, before the critical design review (CDR) or some comparable event.

The timing of the engagements discussed in this report was favorable in 25% of the cases. Non-optimal timing is a major reason that several of the responding programs reported lackluster results. Nevertheless, respondents reported that there was value even though the timing was not optimal and commented that there could be even greater impact if the timing is adjusted.

- "The scenarios which were developed by the architect(s) themselves were more firmly grounded in requirements and therefore usable. The brainstorming nature of the ATAM which relied on stakeholders having a firm understanding of the system was not well-suited to a program with vague and emerging CONOPS [concept of operations] and requirements."

  Here, the timing of the ATAM was too early; although a documented architecture existed, there was enough uncertainty among stakeholders about the goals of the program to make

the ATAM seem less useful to the architects. (Note that this apparent mismatch between architecture development and program goals may, in itself, be a useful revelation.)

- "The ATAM did not have as much impact because most of the work was done up front in our case by the architecture team between QAW and ATAM."
- One program acknowledged the need to use the methods, saying, "ATAMs should be conducted at the initiation of programs where architectural changes can be readily integrated into the program development."
- For one program, the value of the ATAM evaluation was in demonstrating the quality of the architecture to stakeholders rather than in driving architecture development. "As the ATAM/QAW was exercised late in [the] development process, it verified and validated the quality of the architecture to a larger set of representatives within the user space. Secondarily, the ATAM/QAW identified a consistent set of risk themes for tracking by the government and suppliers teams."

In the one case where the ATAM/QAW was reported to be too early in the life cycle, the benefit was reported to be equal to its cost and the engagement resulted in a positive impact on the "architecture construction." When done too late, the ATAM/QAW still delivered value in validating decisions that have been made, although conducting ATAMs earlier in the process would more readily accommodate "architectural changes."

3.3 Need and Motivation

The reasons that programs elected to pursue the ATAM/QAW varied. Generally, reasons for conducting the methods are linked with the acquisition and development processes, especially for dealing with change, managing risk, and establishing priorities. Some of the reasons given for pursuing the methods included the following:

- "To support PMO decision making"
- "It was determined that sufficient stakeholders had changed and there was a need to re-assess the Quality Attribute Tree and related scenarios."
- "The ATAM scenario development activity helped focus available funds on the most important items."
- "The peer review process [meaning the ATAM] helped to identify and prioritize the most critical aspects to transition customers."

Honest objectives alone are not sufficient for maximal impact of the methods, however. Having a genuine need to conduct an ATAM/QAW versus taking advantage of an Army-sponsored (and funded) opportunity to conduct one can significantly affect the perceived benefit and impact of conducting the ATAM/QAW. Using the methods without first determining that they are suitable for the circumstances offers only a hit-or-miss opportunity for receiving value from them. Thus,

need corresponds to whether the ATAM/QAW was appropriate for the situation or whether some other analysis technique would have been more desirable.[5]

There was an appropriate need in most of the programs. Factors that stressed the application of the methods included the need to manage systems of systems, multiple platforms, or research and development projects.

- "[SoS] nonfunctional requirements are much broader than can be handled in a reasonable set of QA scenarios."
- One program "created a specific Arch Evaluation process, leveraging the ATAM but with significant modifications" in order to better meet its particular needs.
- "Architecture was established on multiple platforms . . . Since commonality across platforms is important to cost containment agreement of ALL platforms would be required to make viable changes to the architecture. A users group is and was in existence at which many of the similar issues are raised and discussed for possible implementation."
- "As this was a developmental system under examination, the project was not under any particular pressure to exit with 'fieldable' software."
- "I think the adoption of the practices is a beneficial undertaking; however, this ATAM was applied to a (probably one-time) research and development project that was close to its demonstration phase. Therefore, the practices were not incorporated. If I was starting over, I would consider the ATAM process very favorably."

Using ATAM/QAW at the systems level provided some benefits but pointed to other techniques that are needed (e.g., methods to elicit mission threads and methods to evaluate systems and systems of systems). Research and development projects reported value during the execution of the methods but transition efforts were not applicable in all cases.

No less important than an established need is a level of enthusiasm for the evaluations. The program office needs to be appropriately motivated to arrange for and conduct the ATAM/QAW or it will likely be problematic. If the program office only tacitly or halfheartedly supports the engagement, it will be difficult to motivate key stakeholders to actively participate and make an earnest effort to contribute. Moreover, the program office needs someone to champion the effort and persevere in making the contractual arrangements and bringing the key stakeholders together at an opportune time. Training members of the program office or its representatives as ATAM Evaluators so that they can be part of the ATAM evaluation team would enable them to learn first-hand the value of such engagements and provide motivation to transition the practices.

Where motivation among all stakeholders was highest (in 58% of the programs), comments such as the following were not uncommon.

- "An important factor leading to the success of these activities was a motivated and architecturally educated management and supplier team. Because the team fully accepted the impor-

[5] The SEI has a variety of architecture-centric techniques. Among others, the SEI Mission Thread Workshop (MTW) elicits quality attribute concerns relative to mission threads from a system of systems perspective. The SEI Architecture Improvement Workshop (AIW) is a useful follow-on to an ATAM evaluation that begins with the identified architectural risks and explores ways of mitigating them in a rational, prioritized fashion. The SEI Cost Benefit Analysis Method (CBAM) is a way of analyzing the costs, benefits, and schedule implications of architectural decisions, and can be used by itself or in conjunction with an ATAM evaluation.

tance of identifying nonfunctional or quality based architectural driving requirements it allowed for a more thorough assessment of the architecture for trade space among the requirements and ultimately for its support to the identified set of quality attributes."

- "The ATAM/QAW process and report provided both the government program office and the contracted supplier the confidence and stakeholder support to address follow-on user requirements that far exceeded the original capabilities as implemented within the architecture."

Motivation (or lack of motivation) was related to education in architecture principles (on the part of PMO staff, contractors, and stakeholders), confidence that the methods would yield some positive result, sufficient flexibility in cost and scheduling to make using the results possible, and the existence of formal or informal agreements between the PMO and contractors to perform follow up activities. The following comments are illustrative.

- "It appeared to the stakeholders that these activities did not warrant action since neither the time nor funds were readily available to support them. In addition, it was very questionable as to any impact those activities might have." Stakeholders of this program doubted there was sufficient flexibility in the program to follow through on the evaluation outcomes and dubious about the potential benefits.
- "No mandate to [use quality attribute scenarios] with more robust requirements management and clarifying nonfunctional requirements." On more than one program, absence of agreement between the PMO and contractor prevented full commitment to make use of evaluation results.
- "The architecture was never really taken seriously at the contractor facility." Here again, absence of agreement led to failure to follow through.
- "It is very difficult to change managements' perceptions and the current way of doing business in the government."
- "There are two hindrances to doing more. First is limited understanding of the value outside the software community of 'software things'. . . . The larger hindrance is that PMs are funded to meet system requirements (from requirements documents) in accordance with process requirements (from DoD 5000). PMs are not funded to do things outside those requirements, even if they are great ideas."

3.4 Follow Through

The ATAM identifies risks that need to be integrated into both the program office's and the system developer's standard risk management systems, so that they are appropriately tracked and mitigated. Moreover, it is desirable that these architecture practices be considered for longer term adoption as part of the program office's standard acquisition practices. Longer-term adoption provides additional benefits by leveraging the extensive training Army personnel have received in architecture practices and enabling lessons learned and experiences to be shared across Army programs. In turn, these additional benefits provide an effective basis for initiating a program to evolve and improve acquisition practices for Army programs.

There are many reasons why there may be a lack of follow through, such as

- a political environment that prevents formally tracking new risks

- inadequate expertise in the program office to assess contractor response to engagement results
- inadequate expertise at the contractor to deal with findings of the engagement
- a funding profile that does not support adequate upfront engineering effort

Follow through was high in 42% of the programs. Successful follow through was accomplished because processes were already in place (or put in place) to use the results, several having to do with risk management.

- "The supplier treated each risk theme as a trouble report and attempted to resolve each in a formal process with the Government Architecture team."
- "The adopted practices were incorporated into the program SDP based on recognition of the importance of software architecture practices to program success."
- "The resulting list of QAs was flowed down to lower tier suppliers and required for their architectures to address."
- "Many of these activities were already planned but the ATAM results were incorporated into the processes. Risk management is a required activity and once risks are identified they must be tracked and mitigation strategies developed. Once something is in the database, it must have a mitigation strategy and be tracked."
- "For software, quality attribute requirements and an ATAM-based plan for acceptable satisfaction of quality attributes were specified and tracked in non-traditional but binding RFP documentation."
- "In most cases suppliers and government teams identified products and processes leveraged quality attribute identification, prioritization, modeling, implementation, and test that reflected the intent of the ATAM and QAW processes."
- "[The program] has a risk management process including risk identification and risk mitigation planning. Addressing architecture related risks are part of this process."

In two cases, follow through was seen as a necessary step not only to ensure appropriate architectural decisions but also to further understand system requirements in general.

- "Follow-on refinement of QAW scenarios and generation of new scenarios were necessary to: (1) include the perspective (scenarios and prioritization) of stakeholders not present at the QAW, (2) validate/substantiate QAW scenarios with system architecture and system requirements, and (3) to incorporate changing program business goals and requirements prior to the ATAM and RFP release."
- "Additional scenarios were felt to be important . . . . Software architecture documentation was revised to improve the clarity. The ATAM is now commonly cited in reviews as a validation of proper understanding and refinement of stated requirements."

As noted previously, contractual impediments were a major obstacle to follow through on the evaluation results.

3.5 Other Factors

In addition to the predefined contextual factors noted above, survey responses indicated other factors that affected the impact of the ATAM/QAW, mostly having to do with people and organizational issues.

The training and expertise of the evaluation team (which, in most cases, consisted of SEI facilitators and a mix of SEI and SEI-trained Army evaluators) was cited often. Insufficient levels of trained staff were a clear barrier to continued implementation of the methods.

- "Excellent training and access to very qualified ATAM facilitators."
- "[The program gained] valuable experience . . . from government team (participation on evaluation team)."
- "The program office does not have sufficient numbers of government employees as Core or Matrix support to fully and properly support QAW and ATAM efforts for the life of the program."
- "In the past SEI architecture-level training courses have been identified but due to scheduling constraints could not be attended by members of the team."

Although there is certainly interest in the methods among the Army's software professionals, long-term adoption is limited by a (perceived) lack of need.

- "[The program] does not have any new architecture-based contracts, so there hasn't been a perceived need to establish an ATAM/QAW for new projects."
- "In addition to other cited hindrances, the project is the only software-intensive system within PM. Any additional contracts are only follow-on extensions. There are no new programs coming online at this time. Additional people have been, and continue to be, trained as software architects and evaluators but this is done through their parent organization as professional development rather than through the PM to which they are matrixed as support. This training is encouraged from supervisors in the PM organization when the schedule permits."

Note that many programs obtain software engineering support from one of the Army's software engineering centers (SECs). The existence of these centers suggests that the lack of need is a perceived state of affairs and that awareness of non-software program staffs needs to be raised.

4 Conclusions

This special report describes the results of a study of the impact of software architecture practices conducted with Army programs. Twelve programs that employed the ATAM and/or QAW responded to a questionnaire that addressed the impact of conducting the method, follow-on activities, adoption of the method as part of program practices, and the overall value of the engagement. The consensus of the respondents was that they received value from the QAWs and/or ATAM evaluations conducted for their programs.

Value can be understood in terms of programmatic, product, and practice improvements. Given the appropriate conditions, the ATAM and QAW

- are cost-effective techniques for evaluating software architectures with respect to the architecturally significant requirements
- provide a favorable impact on the understanding of three key development artifacts: the quality attribute requirements of the system, architectural design decisions, and risks driving product development
- foster communication among stakeholders and provide an informed basis for the program office, suppliers, and stakeholders to communicate their needs and understand how they are met

Analysis revealed that the measure of value is influenced by the context in which the practices are used. Programs in more favorable contexts expressed higher perceptions of ATAM/QAW value than programs less favorably situated. It is interesting to note that all programs were able to find some value in their respective experiences. In reviewing the lessons learned, certain patterns of circumstances emerge as leading to higher impact outcomes. These patterns can be understood in terms of the system acquisition life cycle that situates the methods so that the appropriate entry conditions are met, providing favorable circumstances for their application.

The greatest impediment to reaping the maximum benefit from the ATAM architecture evaluations conducted on the Army systems indentified in this report is that the evaluations were primarily done in a reactive mode (i.e., the evaluations were conducted opportunistically and performed under an existing contract as opposed to being pre-planned and incorporated into the RFP/contract from the beginning of the acquisition). The findings provide lessons learned for improving the context through proactive planning, improved execution, and organizational and process support for follow through.

The U.S. Army's Warfighter Information Network-Tactical (WIN-T) was one of the programs surveyed and provides a good example of what is possible given mostly desirable ratings for the contextual factors that influence the impact of the architectural practices. A detailed case study has been written that presents the WIN-T program context, describes the application of the ATAM to the WIN-T system, presents important results, and summarizes the benefits the program received [Clements 2005]. Planning was reactive, requiring accommodation on the part of the program office and contractors to modify the task execution plan, but the other contextual factors were favorable. The case study provides an example of how a government organization can incorporate technologies such as ATAM to solve real problems and improve its mission effectiveness

in a government-owned, contractor-operated environment. A development that attests to the benefits the WIN-T program perceived they received is that the WIN-T program conducted another ATAM later in the life cycle when the program was re-defined and volunteered to pilot the new system and software ATAM that concurrently evaluates both the system and software architecture.

To achieve maximum effectiveness in reducing software acquisition risk, an acquisition organization should be proactive in applying architecture-centric practices. In a proactive approach, architecture-centric practices, such as a QAW and the ATAM software architecture evaluation, are preplanned and integrated up front into the RFP/contract.

Being proactive allows the government to conduct a QAW with government stakeholders during the RFP planning phase. The result of a QAW allows the quality attribute requirements to be included in the RFP, so that they can appropriately drive the contractor's architectural design approach. Following contract award, another QAW can be held in collaboration with contractor stakeholders. This allows for refinement, clarification, and expansion of quality attribute requirements in conjunction with contractor stakeholders such as the chief software architect, domain experts, and software developers.

An effective way to ensure that the proposed architectural design is suitable for achieving the specified system qualities is to require that an ATAM architecture evaluation be conducted prior to a key contractual event such as a traditional DoD PDR or CDR.

The funding provided by ASSIP was the impetus for conducting these evaluations; without that funding, it is unlikely that they would have taken place. If architecture evaluation is to become routine practice within the Army, ASSIP needs to continue to play a leadership role to provide the context that will enable Army programs to proactively apply architecture-centric acquisition practices.

It is recommended that future studies be conducted to measure the impact of architecture evaluations that are conducted proactively. Currently, we know of two DoD programs that proactively included an architecture evaluation in RFP/contracts, one of which is an Army program. A difficulty highlighted in questionnaire responses is the belief that ATAM evaluations will not be routinely performed on Army programs, especially in a proactive mode, unless Army policy mandates it for programs such as Acquisition Category (ACAT) 1 programs.

Appendix A Acronym List

ABCS	Army Battle Command System
ACAT	Acquisition Category
ACS	Aerial Common Sensor
AIW	Architecture Improvement Workshop
APW	Acquisition Planning Workshop
ASSIP	Army Strategic Software Improvement Program
ATAM	Architecture Tradeoff Analysis Method
CAAS	Common Avionics Architecture System
CBAM	Cost Benefit Analysis Method
CDR	critical design review
CECOM	Communications and Electronics Command
CMMI	Capability Maturity Model Integration
CONOPS	concept of operations
COTS	commercial off-the-shelf
CPoF	Command Post of the Future
DCGS-A	Distributed Common Ground Station – Army
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
FBCB2	Force XXI Battle Command, Brigade-and-Below
FCS	Future Combat System
GOTS	government off-the-shelf
IFC	Integrated Fired Control
IPT	integrated product team
JTCW	Joint Tactical Common Operational Picture Workstation
KPP	key performance parameter
MCAP	Manned/Unmanned Common Architecture Program
MTW	Mission Thread Workshop
OneSAF	One Semi-Automated Forces
PD	project director
PDR	preliminary design review
PEO	Program Executive Office
PM	program manager
PMO	program management office
QAW	Quality Attribute Workshop
ROI	Return on Investment
RFP	request for proposal
SDP	System Design Plan
SEC	software engineering center
SED	Software Engineering Directorate
SEI	Software Engineering Institute
SoS	system of systems
SW	software
TCM	TRADOC Capabilities Manager
TRADOC	Training and Doctrine Command
TSM	TRADOC Systems Manager
Win-T	Warfighter Information Network-Tactical

Appendix B About the SEI ATAM and QAW

The two architecture practices that were applied in the engagements with the selected Army programs were the ATAM and QAW.

The Architecture Tradeoff Analysis Method (ATAM)

The purpose of the ATAM is to assess the consequences of architectural decision alternatives in light of quality attribute requirements [Kazman 2000]. The major goals of the ATAM are to

- elicit and refine a precise statement of the architecture's driving quality attribute requirements
- elicit and refine a precise statement of the architectural design decisions
- evaluate the architectural design decisions to determine if they address the quality attribute requirements satisfactorily

The ATAM is predicated on the fact that an architecture is suitable (or not suitable) only in the context of specific quality attributes that it must impart to the system. The ATAM uses stakeholder perspectives to produce a collection of scenarios that define the qualities of interest for the particular system under consideration. Scenarios give specific instances of usage, performance requirements, growth requirements, various types of failures, various possible threats, and various likely modifications. Once the important quality attributes are identified in detail, the architectural decisions relevant to each one can be illuminated and analyzed with respect to their appropriateness.

The steps of the ATAM are carried out in two main phases. In the first phase, the evaluation team interacts with the system's primary decision makers: the architect(s), manager(s), and perhaps a marketing or customer representative. During the second phase, a larger group of stakeholders is assembled, including developers, testers, maintainers, administrators, and users. The two-phase approach insures that the analysis is based on a broad and appropriate range of perspectives.[6]

Phase 1

1. Present the ATAM. The evaluators explain the method so that those who will be involved in the evaluation have an understanding of the ATAM process.
2. Present business drivers. The appropriate system representatives present an overview of the system, its requirements, business goals, context, and the architectural quality drivers.
3. Present architecture. The system or software architect (or another lead technical person) presents the architecture.
4. Catalog architectural approaches. The system or software architect presents general architectural approaches to achieve specific qualities. The evaluation team captures a list and adds to it any approaches they saw during Step 3 or learned during their pre-exercise review of the architecture documentation. For example, "a cyclic executive is used to ensure real-time per-

[6] These two phases are sandwiched by two less intensive phases. Phase 0 is a preparation phase in which the evaluation activities are planned and set up. Phase 3 is a follow-up phase in which the final report is produced and opportunities for improving the process are considered.

formance." Known architectural approaches have known quality attribute properties that will help in carrying out the analysis steps.

5. Generate a quality attribute utility tree. Participants build a utility tree, which is a prioritized set of detailed statements about what quality attributes are most important for the architecture to achieve (such as performance, modifiability, reliability, or security) and specific scenarios that express these attributes.
6. Analyze architectural approaches. The evaluators and the architect(s) map the utility tree scenarios to the architecture to see how it responds to each one.

Phase 2

Phase 2 begins with an encore of the Step 1 ATAM presentation and a recap of the results of Steps 2 through 6 for the larger group of stakeholders. Then these steps are followed:

1. Brainstorm and prioritize scenarios. The stakeholders brainstorm additional scenarios that express specific quality concerns. After brainstorming, the group chooses the most important ones using a facilitated voting process.
2. Analyze architectural approaches. As in Step 6, the evaluators and the architect(s) map the high-priority brainstormed scenarios to the architecture.
3. Present results. A presentation is produced that captures the results of the process and summarizes the key findings that are indicative of what will be in the final report (a product of Phase 3).

Scenario analysis produces the following results:

- a collection of sensitivity and tradeoff points. A sensitivity point is an architectural decision that affects the achievement of a particular quality. A tradeoff point is an architectural decision that affects more than one quality attribute (possibly in opposite ways).
- a collection of risks and non-risks. A risk is an architectural decision that is problematic in light of the quality attributes that it affects. A non-risk is an architectural decision that is appropriate in the context of the quality attributes that it affects.
- a list of current issues or decisions not yet made. Often during an evaluation, issues not directly related to the architecture arise. They may have to do with an organization's processes, personnel, or other special circumstances. The ATAM process records these issues, so they can be addressed by other means. The list of decisions not yet made arises from the stage of the system life cycle during which the evaluation takes place. An architecture represents a collection of decisions. Not all relevant decisions may have been made at the time of the evaluation, even when designing the architecture. Some of these decisions are known to the development team as having not been made and are on a list for further consideration. Others are news to the development team and stakeholders.

Results of the overall exercise also include the summary of the business drivers, the architecture, the utility tree, and the analysis of each chosen scenario. All of these results are recorded visibly so all stakeholders can verify that they have been identified correctly.

The number of scenarios analyzed during the evaluation is controlled by the amount of time allowed for the evaluation, but the process insures that the most important ones are addressed.

After the evaluation, the evaluators write a report documenting the evaluation and recording the information discovered. This report also documents the framework for ongoing analysis discovered by the evaluators. Clements, Kazman, and Klein provide detailed descriptions of the ATAM process [Kazman 2000, Clements 2002].

The Quality Attribute Workshop (QAW)

The QAW is a facilitated method that engages system stakeholders early in the life cycle to discover the driving quality attributes of a software-intensive system. It provides a means to generate, prioritize, and refine quality attribute scenarios before the software architecture is completed. The QAW is focused on system-level concerns and specifically the role that software will play in the system.

The QAW involves the following steps:

1. QAW Presentation and Introductions. The facilitator explains the method so that those who will be involved in the workshop have an understanding of the QAW process.
2. Business/Mission Presentation. The appropriate system representatives present an overview of the system, its requirements, business goals, context, and the architectural quality drivers.
3. Architectural Plan Presentation. The system or software architect (or another lead technical person) presents the architectural plan.
4. Identification of Architectural Drivers. The facilitation team captures information regarding architectural drivers that are key to realizing quality attribute goals in the system. These drivers often include high-level requirements, business/mission concerns, goals and objectives, and various quality attributes.
5. Scenario Brainstorming. The stakeholders brainstorm scenarios that express specific quality concerns.
6. Scenario Consolidation. The stakeholders consolidate similar scenarios before they are prioritized.
7. Scenario Prioritization. The stakeholder chooses the most important scenarios using a facilitated voting process.
8. Scenario Refinement. The stakeholders further elaborate the high-priority brainstormed scenarios.

Scenario refinement produces the following results:

- Business and mission goals affected by the scenario.
- Quality attributes associated with the scenario.
- A concrete description of the scenario in terms of: (1) the stimulus that affects the system; (2) the response that results from the stimulus; (3) the entity that generated the stimulus; (4) the environment under which the stimulus occurred; (5) the artifact that was stimulated; and (6) the measure by which the system's response will be evaluated.
- Questions and issues raised by the stakeholders regarding the scenario. Such questions and issues concentrate on the quality attribute aspects of the scenario and any concerns that the stakeholders might have in achieving the response called for in the scenario.

Results of the overall exercise also include the summary of the business drivers, the architectural plan, the collection of brainstormed scenarios, and the refinement of each chosen scenario. All of these results are recorded visibly so all stakeholders can verify that they have been identified correctly.

The number of scenarios refined during the workshop is controlled by the amount of time allowed for the refinement, but the process insures that the most important ones are addressed.

After the workshop, the facilitators write a report documenting the workshop and recording the information discovered. Barbacci and other provide a description of the QAW process [Barbacci 2003].

Appendix C ATAM/QAW Impact Questionnaire

June 23, 2008

RE: [*system*] [*QAW/ATAM*] held [*date*]

The Office of the Assistant Secretary of the Army (Acquisition, Logistics, and Technology) has asked us to interview personnel from programs that have had Architecture Tradeoff Analysis Method® (ATAM®) or Quality Attribute Workshop (QAW) engagements with the Software Engineering Institute (SEI). Our goal in contacting you is to gauge the impact that the engagement had on the quality of the system and the practices of your organization. In order to understand impact, we are collecting follow-on data from all of the participating programs via a short questionnaire and a subsequent interview.

We are asking you to complete the enclosed questionnaire and return it within two weeks. We estimate it will take no more than an hour. For your convenience, you may either edit the Microsoft Word file directly or print out a copy and fill in the responses. If you edit the document online, you can highlight an empty check box, and type the letter "x" to check the box. Please take time to respond to the open-ended questions. These provide an opportunity for you to explain the rationale for your checked responses.

Please be candid in your responses and complete this questionnaire as best you can. If you are uncertain about an answer, or if you are reporting the view of a colleague, please indicate this as part of your response. We are looking for your best reasoned estimates and responses.

We will aggregate and analyze the data from all respondents. The results will be described in a report that will be sent to our sponsor, Mr. Robert Schwenk, Senior Software Acquisition Manager, ASA(ALT). The report will identify the collection of participating programs responding to the survey but your specific data will not be identified with your specific program. Our overall goal is to assess the value and impact of architecture-centric acquisition practices to the Army.

Thanks for your help. Your cooperation is important and we value your feedback.

John Bergey, Stephen Blanchette, Mark Klein, Robert Nord

Software Engineering Institute

Encl: questionnaire

This questionnaire has four sections that address (1) conducting the ATAM/QAW, (2) follow-on ATAM/QAW activities, (3) adoption of ATAM/QAW as part of program practices, and (4) overall value of the engagement. The questions in these sections address the impact of the engagement on the quality of the system and the practices of the involved program office, stakeholders, and suppliers.[7]

I. Conducting the ATAM/QAW

The ATAM/QAW produces and uses quality attribute (nonfunctional) requirements, architecture documentation, and architecture risks.

Please indicate the extent to which you believe that conducting the ATAM/QAW	Minimal	Moderate	Significant	Very Substantial
a. Clarified quality attribute requirements	❑	❑	❑	❑
b. Discovered new quality attribute requirements	❑	❑	❑	❑
c. Exposed architecturally significant (high-priority and high-impact) requirements	❑	❑	❑	❑
d. Improved the understanding of the architecture	❑	❑	❑	❑
e. Described new views or architectural approaches	❑	❑	❑	❑
f. Exposed key design decisions that provided additional insight into the architecture	❑	❑	❑	❑
g. Clarified understanding of existing tradeoffs	❑	❑	❑	❑
h. Discovered new tradeoffs	❑	❑	❑	❑
i. Exposed important tradeoffs that impacted achievement of business and mission goals	❑	❑	❑	❑
j. Clarified understanding of existing risks	❑	❑	❑	❑
k. Discovered new risks	❑	❑	❑	❑
l. Exposed high-priority risks that impacted achievement of business and mission goals	❑	❑	❑	❑
m. Improved the architecture	❑	❑	❑	❑
n. Fostered communication among stakeholders	❑	❑	❑	❑
o. Provided an informed basis for the program office and the supplier to better understand and control the software development cost and schedule	❑	❑	❑	❑
p. Provided an informed basis for the program office to specify quality attribute requirements, understand the software design, and evaluate systems to ensure achievement of business and mission goals	❑	❑	❑	❑

[7] Note that the term *supplier* refers to the organization responsible for supplying the software, which could be a contractor, subcontractor, software engineering center, or other software development organization.

q. Provided an informed basis for the supplier to understand quality attribute requirements, use them to make and evaluate architecture decisions, and improve the architecture	❑	❑	❑	❑
r. Provided an informed basis for stakeholders to communicate requirements and understand how they were represented and met	❑	❑	❑	❑
s. Other (please identify):	❑	❑	❑	❑

t. Comment:

II. Follow-On ATAM/QAW Activities

The following sections provide examples of activities that might have occurred after and as a consequence of the ATAM/QAW engagement.

1. Specification and Use of System Quality Attributes

Please check whether or not the activity was conducted.	Yes	No
a. Additional quality attribute scenarios were refined that were identified during the QAW	❑	❑
b. Additional quality attribute scenarios were analyzed that were identified during the ATAM	❑	❑
c. Additional quality attribute scenarios were identified after the ATAM/QAW	❑	❑
d. Quality attribute scenarios were incorporated into the requirements baseline	❑	❑
e. Quality attribute scenarios were put into a requirements tracking system	❑	❑
f. Documentation containing the quality attribute requirements was created or improved	❑	❑
g. Quality attribute scenarios were adopted as the preferred means of specifying the system's nonfunctional requirements	❑	❑
h. Quality attribute scenarios were used in the RFP, and/or in negotiations with the supplier	❑	❑
i. Quality attribute scenarios were used in the development of the architecture	❑	❑
j. Quality attribute scenarios were used in conducting architecture walkthroughs	❑	❑
k. Other (please identify):	❑	❑

l. Please describe why you conducted the activities indicated by "yes." What was the realized benefit? What factors enabled or contributed to the success of performing these activities?

m. Please describe why you did not conduct the activities indicated by "no." Even though not performed, is there a perceived benefit to doing so? What were the obstacles that hindered you from doing so?

2. Documentation and Use of Software Architecture

Please check whether or not the activity was conducted.	Yes	No
a. The improvements to the architecture were incorporated into the architecture documentation	❑	❑
b. The program office was able to use the documented architecture more effectively	❑	❑
c. The documented architecture was used to evaluate future/other changes to the architecture	❑	❑
d. The supplier was required to place the software architecture description document under formal configuration management control	❑	❑
e. The supplier was required to formally deliver the software architecture description document to the program office	❑	❑
f. The supplier was required to include the software architecture in its descriptions of bi-directional traceability	❑	❑
g. Other (please identify):	❑	❑

h. Please describe why you conducted the activities indicated by "yes." What was the realized benefit? What factors enabled or contributed to the success of performing these activities?

i. Please describe why you did not conduct the activities indicated by "no." Even though not performed, is there a perceived benefit to doing so? What were the obstacles that hindered you from doing so?

3. Identification and Management of Architecture Risks

Please check whether or not the activity was conducted.	Yes	No
a. Additional risks were subsequently identified as a result of conducting additional ATAM analysis	❑	❑
b. The status and disposition of some or all the risks that were identified were tracked	❑	❑
c. The program office oversaw the mitigation of risks and/or risk themes	❑	❑
d. The program office entered risks and risk themes into its standard risk management system and processed them accordingly	❑	❑
e. The program office met with the supplier to discuss risks and risk themes and their resolution	❑	❑
f. Risks and risk themes were discussed during PDR, CDR or some other program technical review	❑	❑
g. The risk mitigation results were documented	❑	❑
h. The supplier entered risks and risk themes into its standard risk management system and processed them accordingly	❑	❑
i. A formal risk mitigation plan was developed to describe how the risks and risk themes should be mitigated	❑	❑
j. The supplier was required to conduct an architectural walkthrough to demonstrate that the risks were appropriately mitigated	❑	❑
k. The supplier was required to identify the changes to the architecture description document and the architecture documentation was updated in accordance with the risk mitigation results	❑	❑
l. Identified risks were successfully mitigated resulting in an improved architecture	❑	❑
m. Other (please identify):	❑	❑

n. Please describe why you conducted the activities indicated by "yes." What was the realized benefit? What factors enabled or contributed to the success of performing these activities?

o. Please describe why you did not conduct the activities indicated by "no." Even though not performed, is there a perceived benefit to doing so? What were the obstacles that hindered you from doing so?

III. Adoption of ATAM/QAW as part of Program Practices

The following list provides examples of how the ATAM/QAW engagement might have affected the long-term acquisition practices of the program office, program office stakeholders, system stakeholders, and/or suppliers.

Please check one of the boxes for each practice, noting whether you have adopted the practice, plan to adopt the practice, or do not plan to adopt the practice:	Adopted Practice	Plan to Adopt	Do Not Plan to Adopt
a. Quality attribute scenarios will be (are being) adopted as the means for specifying the system's nonfunctional requirements	❑	❑	❑
b. A Quality Attribute Workshop (QAW) will be (is being) conducted with program stakeholders to specify a system's nonfunctional requirements	❑	❑	❑
c. A software architecture description document will be (is) a required contractual deliverable	❑	❑	❑
d. Architecture evaluations will be (are being) adopted as the means for identifying architecture risks early in the acquisition life cycle	❑	❑	❑
e. The ATAM will be (is being) used to conduct architecture evaluations on major upgrades or new systems the program office or its stakeholders will be responsible for	❑	❑	❑
f. On new contract starts, a QAW will be (is being) proactively specified in the RFP/contract as part of the up-front acquisition planning process	❑	❑	❑
g. On new contract starts, an ATAM will be (is being) proactively specified in the RFP/contract as part of the up-front acquisition planning process	❑	❑	❑
h. PMO and supplier will be (are) negotiating changes to requirements based on a better understanding of program constraints	❑	❑	❑
i. Suppliers will be (are being) contractually required to produce a formal architecture risk mitigation plan	❑	❑	❑
j. Program office and or supplier personnel will be (are being) appropriately trained so they can be part of the ATAM Evaluation Team	❑	❑	❑
k. Additional program office personnel will take (are taking) training to become SEI-certified ATAM Evaluators	❑	❑	❑
l. Other (please identify):	❑	❑	❑

m. Please describe why you adopted or plan to adopt the practices noted. What was the realized benefit? What factors enabled or contributed to the success of performing these practices?

n. Please describe why you did not adopt the practices you noted. Even though not performed, is there a perceived benefit to doing so? What were the obstacles that hindered you from doing so?

IV. Overall Impact

In view of the entire engagement, the following sections address the impact of the ATAM/QAW in terms of the effects on up-front cost and schedule and longer term value in terms of cost savings (avoidance), schedule, quality, and capability improvements.

1. Cost, Schedule, and Quality Impact

If the ATAM/QAW had not been conducted, some level of effort would have been spent on eliciting and specifying the nonfunctional (e.g., quality attribute) requirements and evaluating the software design (e.g., peer reviews, walkthroughs) using other means.

	Less	Same	More
Please answer the following two questions from the perspective of using your other means to achieve the *same level of quality* that you realized from conducting the ATAM/QAW:			
a. Compared to the likely effort that would have been expended, the ATAM/QAW was less, the same, or more effort	❑	❑	❑
b. Compared to the likely cost that would have been incurred, the ATAM/QAW was less, the same, or more cost	❑	❑	❑
Please answer the following two questions from the perspective of using your other means as you *traditionally* do:			
c. Comparing the quality of the results of other means used for eliciting and specifying the nonfunctional requirements, the ATAM/QAW produced results (e.g., quality attribute scenarios) that were less, the same, or more quality	❑	❑	❑
d. Comparing the quality of the results of other means used for evaluating software design, the ATAM produced results (e.g., quality attribute scenarios, architecture documentation, and architectural risks) that were less, the same, or more quality	❑	❑	❑

e. What data is being collected to support your answers noted above? Can you provide a more quantitative response to the above questions?

f. Comments:

2. Long-Term Value of the ATAM/QAW Results

Based on your experience please provide your best reasoned estimate of the value your program received from the ATAM/QAW experience and results (e.g., better and earlier identification of quality attribute requirements, documentation of architecture design decisions, and discovery of architecture risks):

	Minimal	Moderate	Significant	Very Substantial
a. System Quality Improved—positive impact on system acceptance and usability through ability to provide the affected qualities	❑	❑	❑	❑
b. Program Schedule Performance Improved—positive impact on controlling schedule (e.g., minimizing scale of the added schedule delay that would otherwise have been required downstream had the risks not been discovered early)	❑	❑	❑	❑
c. Program Cost Performance Improved—positive impact on controlling cost (e.g., minimizing scale of the cost associated with the rework effort that would otherwise have been required downstream had the risks not been discovered early)	❑	❑	❑	❑
d. Warfighter Effectiveness Improved—positive impact on mission goals through ability to provide the affected capabilities and qualities	❑	❑	❑	❑

e. What data is being collected to support your answers noted above? Can you provide a more quantitative response to the above questions?

f. Comments:

3. Summary

a. What, in your opinion, was the overall impact of the ATAM/QAW on the architecture?

b. What, in your opinion, was the overall value of the ATAM/QAW? Do you feel the benefit exceeded its cost?

c. Are there any other comments that you wish to share?

Appendix D Raw Responses Regarding Impact

Captured in this appendix are the raw responses to the last three questions of the survey, which were open-ended questions seeking to elicit a qualitative sense of overall value. The responses are provided for completeness.

1. What, in your opinion, was the overall impact of the ATAM/QAW on the architecture?
2. What, in your opinion, was the overall value of the ATAM/QAW? Do you feel the benefit exceeded its cost?
3. Are there any other comments that you wish to share?

Program 1

- On an existing architecture across multiple platforms across multiple services, the ATAM process is not effective, due to cost and schedule constraints. Individual platform changes to architecture [are] costly and schedule intensive, with severe impacts on training and the logistics tail.
- No.
- The ATAM was performed to determine if it could be incorporated into the development effort. Unfortunately, due to the breath of impact of the architecture, the results were not amenable to implementation except at great cost and time. ATAMs should be conducted at the initiation of programs where architectural changes can be readily integrated into the program development. The [program] community is aware, and has been for some time, of changes to the architecture which would improve the product. Finding the means to implement these changes without bankrupting the efforts is the difficulty.

Program 2

- The ATAM and QAW had a positive impact to the DoDAF architecture construction, but no impact on the contracted efforts.
- The benefit of the ATAM was equal to its cost. The ATAM was conducted too soon in the system life cycle.

Program 3

- The contractor team was already doing very good work on the software architecture prior to the ATAM. I think the peer review was positive in that it challenged some of the developers' thinking and helped everyone better understand the capabilities we were trying to achieve. There is no doubt that the project office exited the activity with a better understanding of the requirements and how we intended to satisfy them.
- The benefit was significant and exceeded the costs. The software has demonstrated great utility and flexibility. What is more, the system has transitioned to a critical, high profile helicopter upgrade program.
- The SEI did a very good job presiding over, facilitating, and leading our ATAM. They have very highly qualified technical experts and have laid out a process that proved to be very beneficial to us.

Program 4

- For the ATAM portion of the process, which is the scope of this response, the impact was minimal.
- I do not think the ATAM itself gave us a net positive return on investment. It did help with stakeholder communication, but ungrounded QA inputs and functionality expectations in the form of scenarios from stakeholders required extra non-value added work. Architecture Evaluations accordingly to the modified [program] process have been very valuable.
- This particular QAW was very large (~80 participants). The architects were experienced and had detailed quality attribute definitions from past programs that were adapted for use on [the system]. The brainstorming method of identifying QAs in the QAW was therefore unnecessary and of lower quality than the detailed analysis which formed the basis of the prior work. Many of the scenarios postulated by participants were unrealistic and unnecessary to meet vague and emerging program requirements. So there was a strong sense of "unreality" in the scenarios, and the QA inputs from stakeholders lacked depth.
- From a technical perspective then, the QAW served more as a review of the proposed QAs than a means of defining them. The SEI facilitators were experienced and conducted the QAW well. A tailoring of the QAW was coordinated with them beforehand to meet the unprecedented scale of this QAW, but then a ruling from the SEI came down that it could not be called a "QAW" unless it followed the standard process verbatim. This was unfortunate and led to wasted effort in the workshop.
- As a result of the above, the value of the QAW was socio-political. It got the stakeholders to agree on the QAs, even though the scenarios did not survive. It allowed the program to state that it had followed a standard process in doing so. The resulting QAs were established in a stable manner and have formed a good basis for the [program]-specific architecture evaluation process.

Program 5

- As the ATAM/QAW was exercised late in [the system's] development process, it verified and validated the quality of the architecture to a larger set of representatives within the user space. Secondarily, the ATAM/QAW identified a consistent set of risk themes for tracking by the government and suppliers teams.
- Although I do not have a specific cost value to tie to the ATAM, the ATAM/QAW was beneficial to strengthen the quality attribute identification and architecture development processes and I believe the benefits far exceeded the costs. The ATAM/QAW process is essential early in the development of complex, software-intensive systems for consistent stakeholder (user, supplier, management) requirement (functional and nonfunctional) focus, design, implementation, and acceptance. Continued architecture maintenance and quality attribute alignment/sustainment is also viewed as necessary component of the greater software life-cycle management process.
- Overall, the ATAM/QAW was beneficial to [the program] as it provided an independent, rigorous means of assessing the architecture from a use case, quality attribute perspective in front of a multitude of stakeholders. This assessment provided valuable, high-quality insight into the risks and non-risks associated with the architecture in meeting the stakeholder needs

and requirements. Finally, the ATAM/QAW process and report provided both the government program office and the contracted supplier the confidence and stakeholder support to address follow-on user requirements that far exceeded the original capabilities as implemented within the architecture.

- The ATAM/QAW is highly recommended for new software-intensive projects committed to engaging their stakeholder community, practicing sound software architecture and developmental processes, and exercising a meaningful risk identification and management process. Even for ongoing projects the ATAM/QAW process is very beneficial for an independent assessment of architecture products and a structured process for identifying architecture-related risks and non-risks.

Program 6

- The ATAM did not have as much impact because most of the work was done up front in our case by the architecture team between [the conducting of the] QAW and ATAM. The two QAWs we held had significant impact that drove the architecture with respect to level of embedded-ness, abstraction layers, and modularity from what we had before.
- Gathering all the stakeholders in one room in itself was a huge benefit. QAW, ATAM did not exceed its cost, if anything we should have done more of them to continually reconfirm nonfunctional requirements, update the architecture, and get buy-in to the architecture.
- Product line requires wholesale changes in PMO ways of doing business from technical, business, and requirements (TRADOC Capabilities Manager [TCM]) perspective first; otherwise, there is no hope a defense contractor will never change. Another comment is there needs to be competition and multiple sources for [software] SW modules up front; otherwise, I feel we are not fully leveraging a documented, modular architecture if we keep going to one source and expect to meet our strategic goals: better, faster, cheaper.

Program 7

- The overall impact of the ATAM/QAW on the system architecture was positive. It was positive primarily because the process requires the supplier architecture team to explain to evaluators/stakeholders how the proposed system architecture would respond in various scenarios.
- No, the system architecture was changed where appropriate to address the resultant risk themes. The insertion of an ATAM-like process earlier in the development did find risks early and thus would have reduced long-term cost.
- In [the respondent's] opinion, a system ATAM-like process could have a significantly positive impact to the construction of the Department of Defense Architecture Framework (DoDAF) architectural artifacts developed by the Program Managers and the TRADOC System Managers (TSM). The current ATAM process is for software and obtains its strength via the originators' understanding of the applicability of software patterns. At the higher level DODAF architectural abstractions, knowledge domain for such enterprise patterns is a dark and empty void. We had no comments on patterns.

Program 8

- QAWs and ATAMs had a positive impact on decision making with risk themes and tradeoffs that could be analyzed to influence future architecture vision.
- Structured, repeatable process to understand risk in architectural approaches
- Both ATAMs and QAWs provided exceptional overall value for achieving Army goals with joint programs.

Program 9

- QAWs and ATAMs had a positive impact on decision making with risk themes and tradeoffs that could be analyzed to influence future architecture vision.
- Structured, repeatable process to understand risk in architectural approaches
- Both ATAMs and QAWs provided exceptional overall value for achieving Army goals with joint programs.

Program 10

- The QAW and ATAM were intended to understand the design decisions made regarding the architecture of an existing system and explore growth scenarios to evolve that architecture to a future system. The application (via contracts) of the QAW realized quality attribute requirements and ATAM-based evaluations will impact the shape of the architecture of future systems.
- The overall value of the ATAM/QAW is that several specific activities were initiated that will affect future architectures. These include
  - ATAM-identified risks and mitigation suggestions were incorporated into the program risk database.
  - An ATAM-based Software Architecture Evaluation Plan was written and incorporated into an acquisition program.
  - The QAW process (whose proponent was initially the software group) was subsequently adopted by System Engineering, and a second QAW (post-ATAM and not facilitated by SEI) was held.
  - QAW results were utilized to explore use cases and as a basis for development of non-functional System Specification requirements.
  - Benchmarking of key technologies and products identified [by means of the] ATAM as risks were initiated or expanded.
  - QAW use case operational scenarios were examined for substantiation in the System Architecture.

Program 11

- Existing documentation was improved and documentation thereafter was of better quality. With a better understanding of the requirements, further refinement of the architecture went smoother.
- The largest impact was improved understanding and communications. This was particularly true since we had just merged two competing contracts into a single partnering contract. This

resulted in a variety of process improvements that have been resulting in better development and a better understanding, resulting in cost savings through less rework.

- Full implementation of the ATAM/QAW process will not happen until it is added to the processes required by DoD 5000.[8] The same holds true of other ASSIP efforts. PMs do what PMs are funded to do, and PMs are funded to meet requirements.
- Contracts are follow-on extensions. No new programs [are] coming online.

Program 12

- QAWs and ATAMs had a positive impact on decision making with risk themes and tradeoffs that could be analyzed to influence future architecture vision.
- Structured, repeatable process to understand risk in architectural approaches
- Both ATAMs and QAWs provided exceptional overall value for achieving Army goals with joint programs.

[8] DoD 5000.01 details the policies that govern the U.S. DoD acquisition system; DoD 5000.02 details the management framework that implements those policies.

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13. ABSTRACT (MAXIMUM 200 WORDS)

The Army Strategic Software Improvement Program (ASSIP) is a multiyear effort targeted at improving the way in which the Army acquires software-intensive systems. The ASSIP has funded a number of programs, in conjunction with the Carnegie Mellon® Software Engineering Institute (SEI), to conduct software architecture evaluations using the Architecture Tradeoff Analysis Method® (ATAM®). Additionally, in cases when a system's architecture did not exist or was not ready to evaluate, the ASSIP sponsored Quality Attribute Workshops (QAWs). During the period of this effort, several other programs funded their own ATAM evaluations and QAWs. The goal of this study was to determine the benefits associated with using the ATAM and QAW.

This special report describes the results of a study of the impact that the ATAM evaluations and QAWs had on Army programs. All 12 programs that used the ATAM and/or QAW responded to a questionnaire whose objective was to determine the impact of the experience in terms of the quality of the system, the practices of the involved program office, stakeholders, and suppliers, and the overall value of the engagement.

The data gathered confirms that the use of ATAM-based architecture evaluations and QAWs are generally beneficial to system acquisitions and suggests that maximal benefit is achievable only if architecture-centric practices are built into the acquisition process.

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